Probing the cosmic evolution of radio AGNs by the radio luminosity function

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Yunnan Observatories, CAS

YNAO is located in the “spring city” of Kunming, Yunnan province

YNAO has a total of ~ 240 (as of June 2013) employees, of which 210 are research-related personnel, and 122 graduate students.

See http://english.ynao.cas.cn/ for more details

Telescopes & Instrumentation

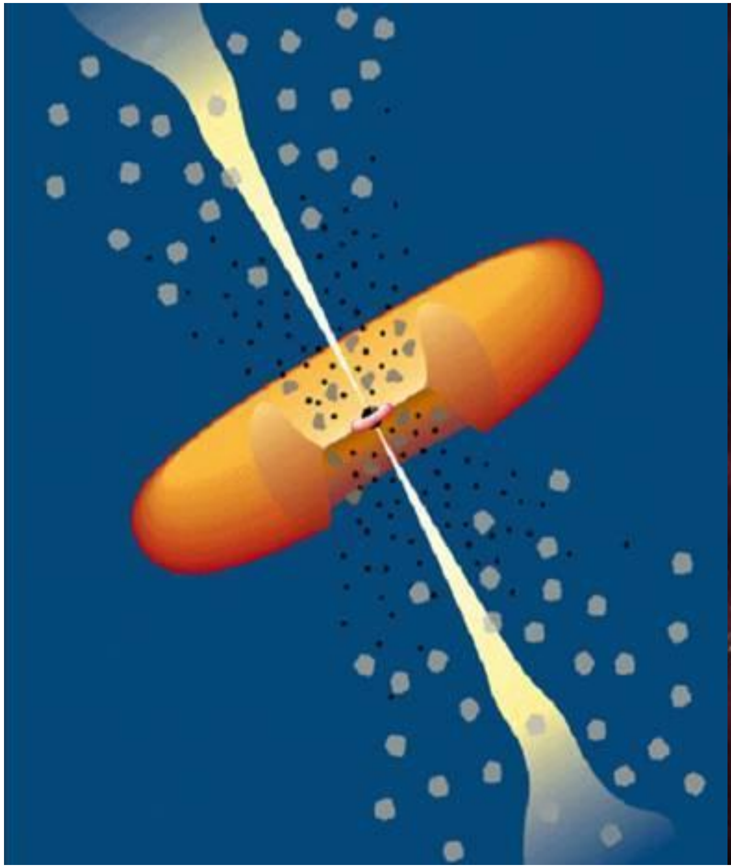
2.4m Telescope

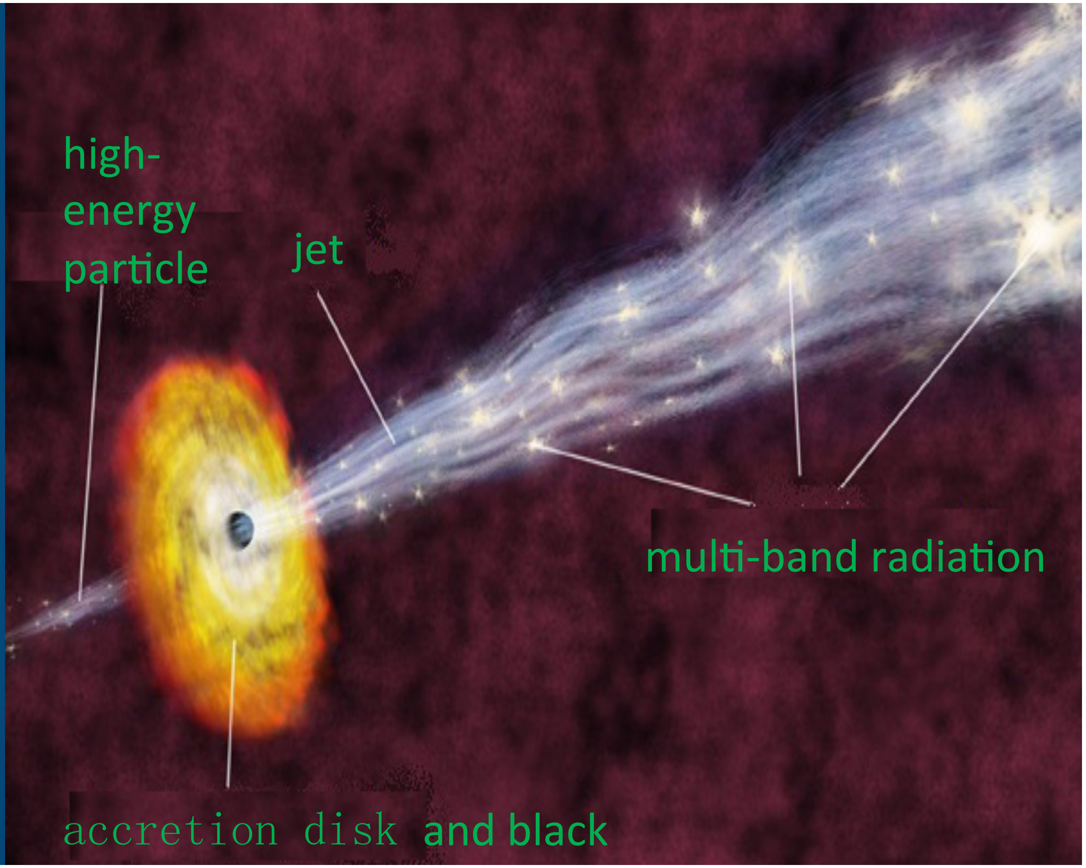
New Vacuum Solar Telescope

1m Telesope

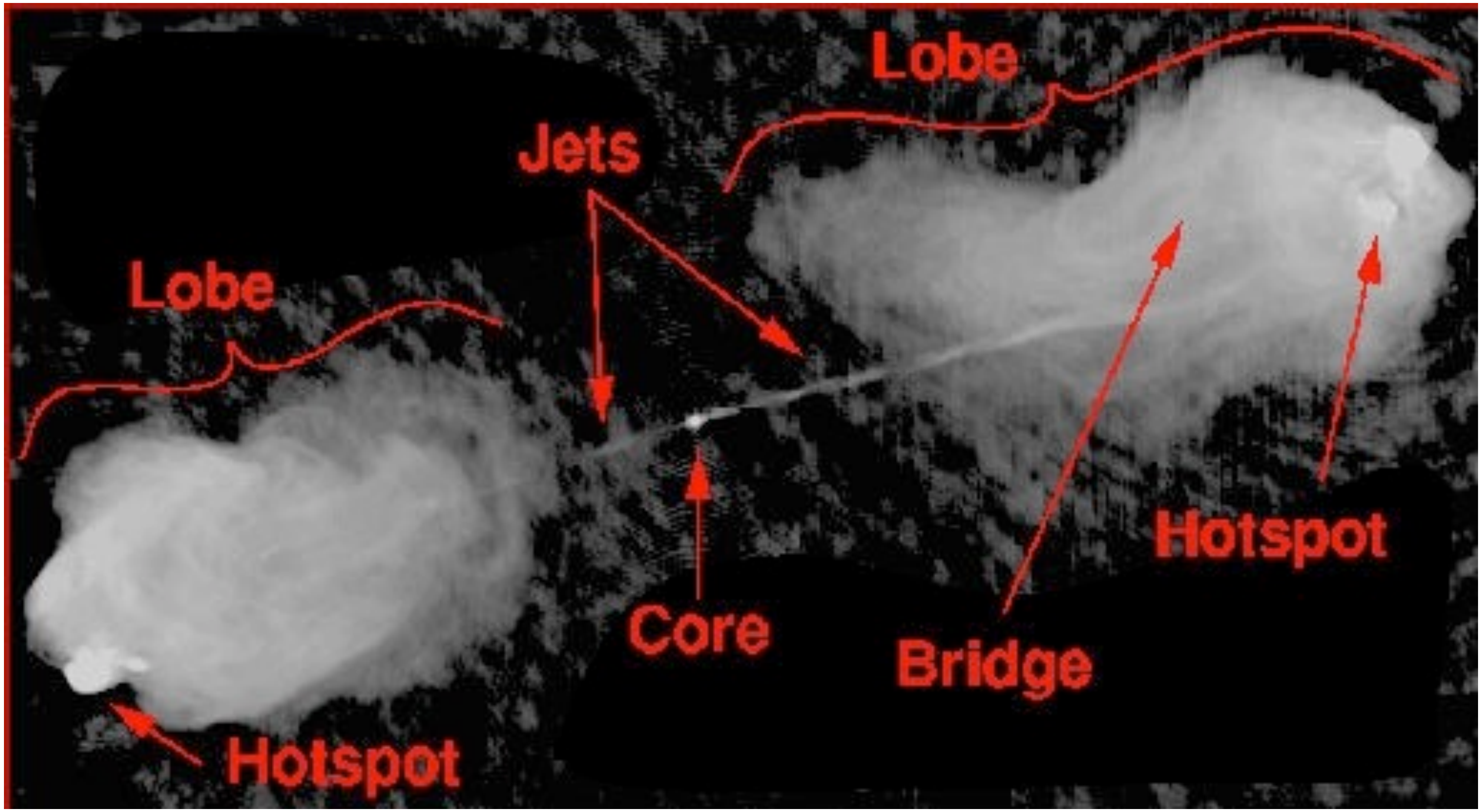
40m Radio Telescope

What is an AGN (active galactic nucleus)?



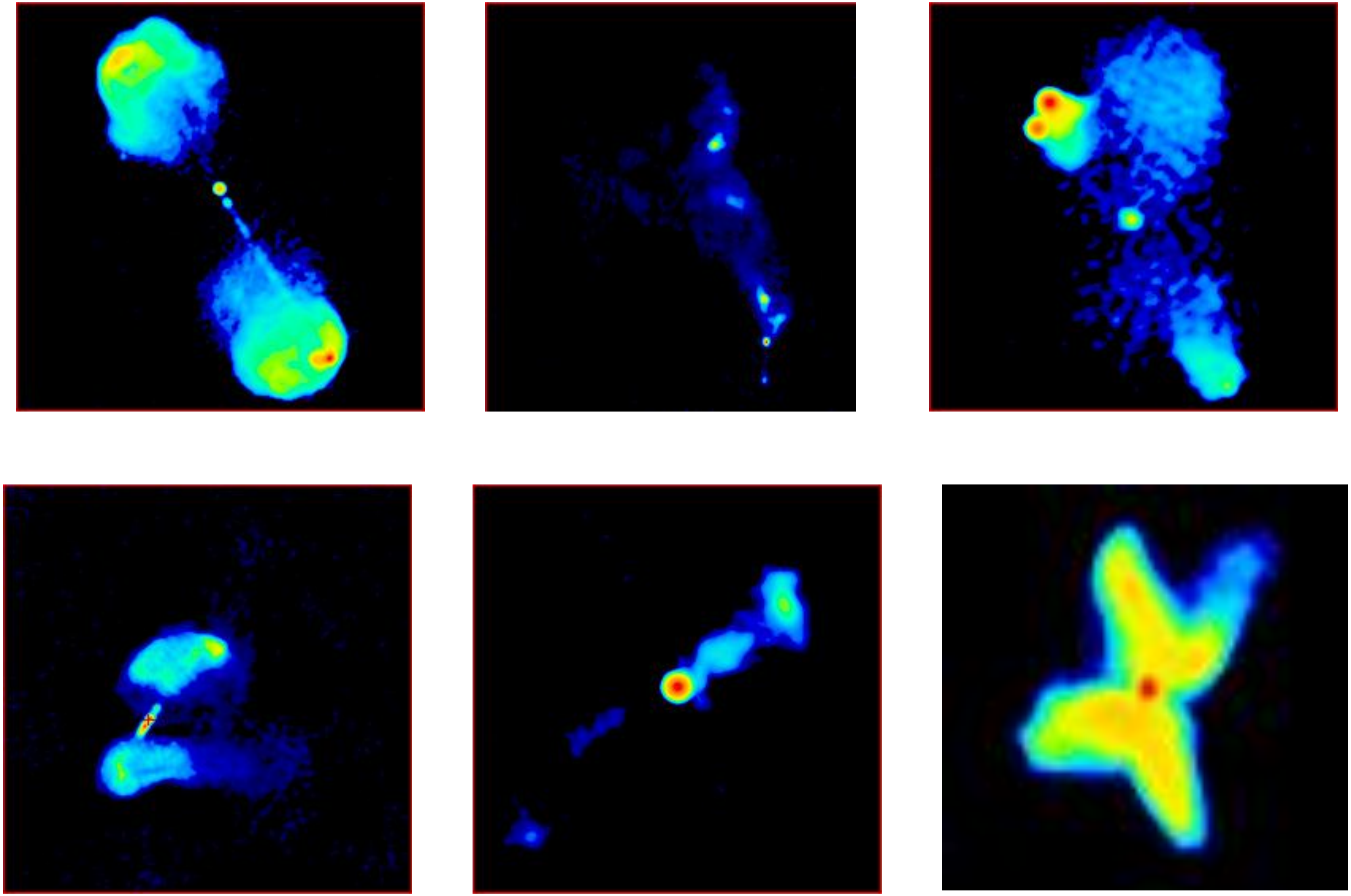


radio AGNs



Only about 10% AGNs have strong radio emission, known as radio-loud AGNs.

Various morphologies of radio AGNs



All figures derived from 3CRR Atlas

The radio luminosity function of AGNs

- The luminosity function $\phi(L,z) = \frac{d^2N}{dVdL}(L,z)$

- It has been an important and also common tool for understanding the evolution of galaxies and AGNs.

- The radio luminosity function （RLF） has the advantage of being free from dust obscuration. It is an ideal tool to measure the cosmic evolution of AGNs to high redshift.

Some key scientific issues

- AGN evolve strongly, i.e., their LF changes with redshift, with their powers and/or they numbers being different from what they are at z ~0. But what's the nature of evolution?
- Whether such an evolution is purely due to space density evolution or due to luminosity evolution (the evolution degeneracy);
- Is there a clear evidence for a decline of the comoving space density of radio AGNs at high redshifts? (the redshift cut-off prbleam)

Some difficulties in estimating the RLF

- 1. Sample completeness

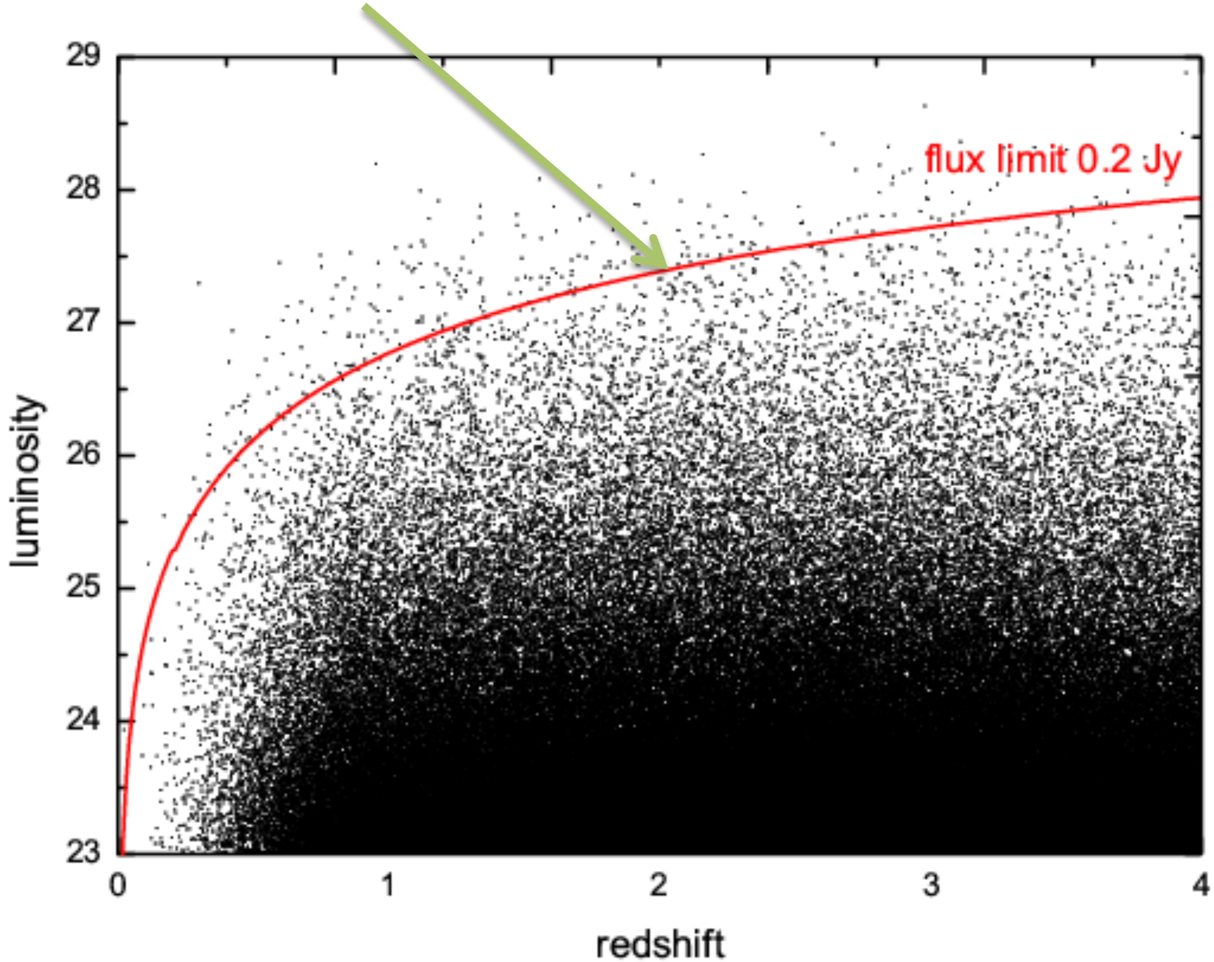
E.g., flux limited complete sample

- 2. K-correction

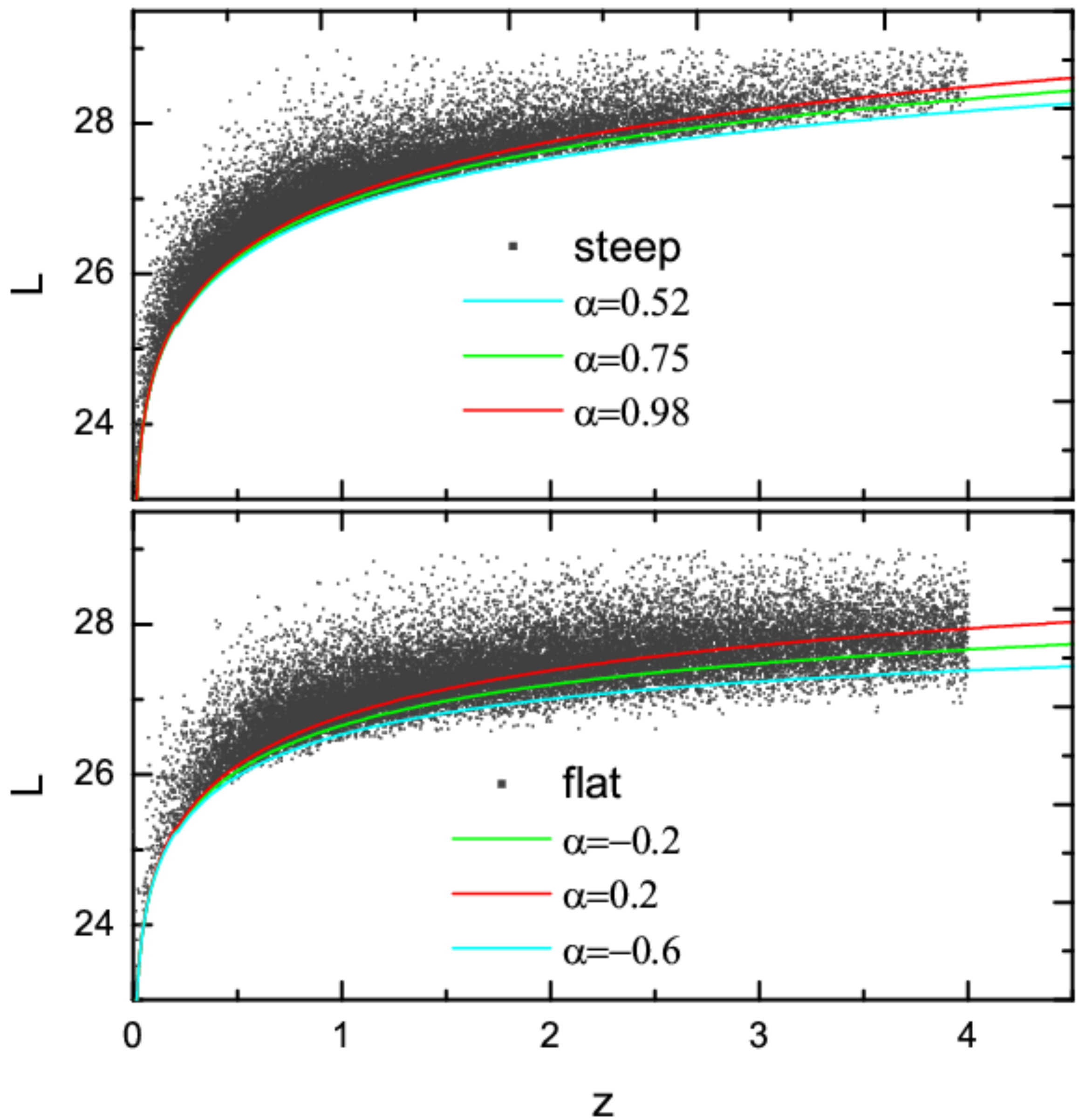
It not only affects the accurate determination of intrinsic luminosity of individual sources, but also complicates the process of translating flux selection limits into luminosity selection limits.

For the radio source: $S \propto \nu^{-\alpha}$ and $K(z) = (1+z)^{1-\alpha}$

- 3. Treat the truncation boundary properly truncation boundary: because the spectral index of a sample has a distribution， in fact the truncation boundary is not a curve， but a region.



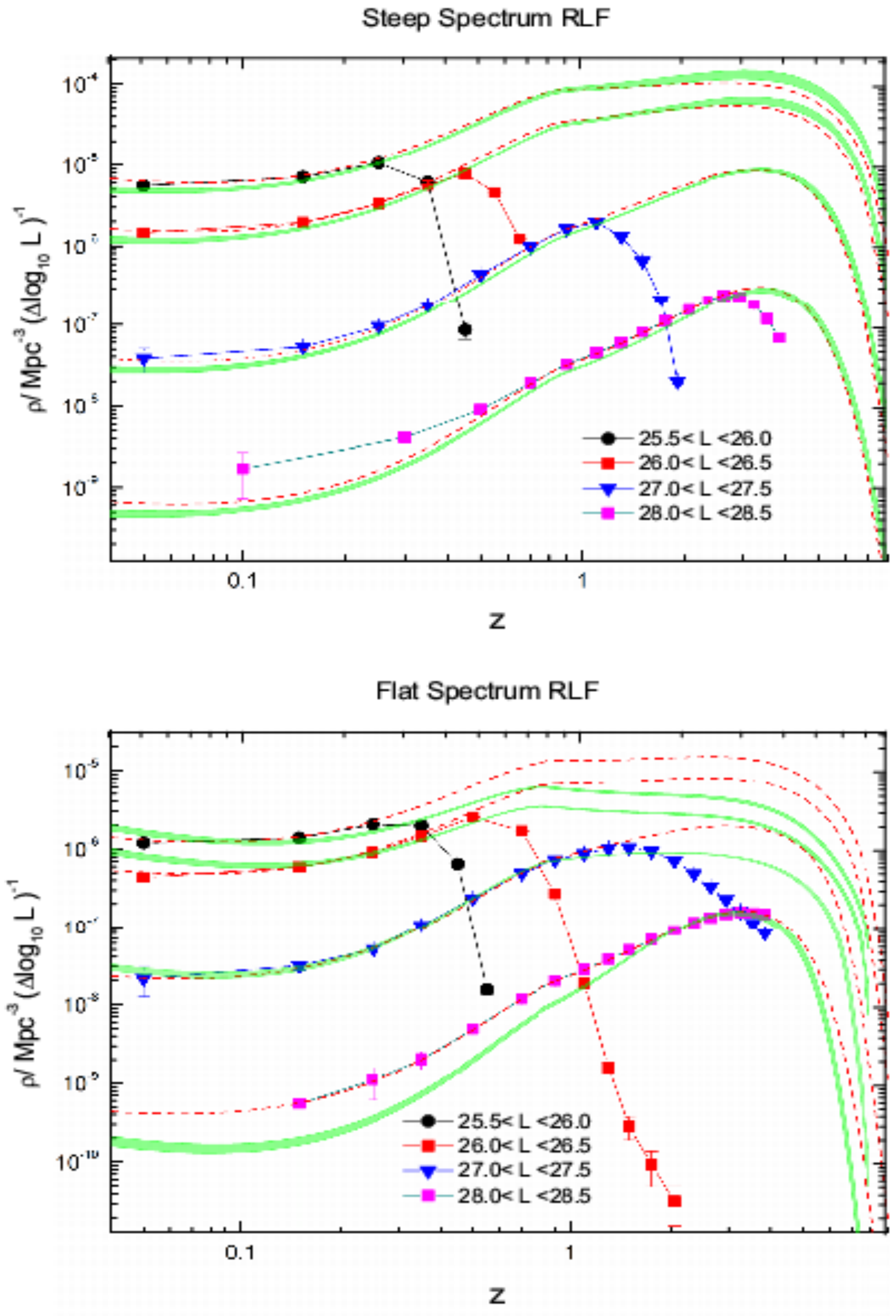
In an actual survey, only a very limited number of objects in the universe can be observed

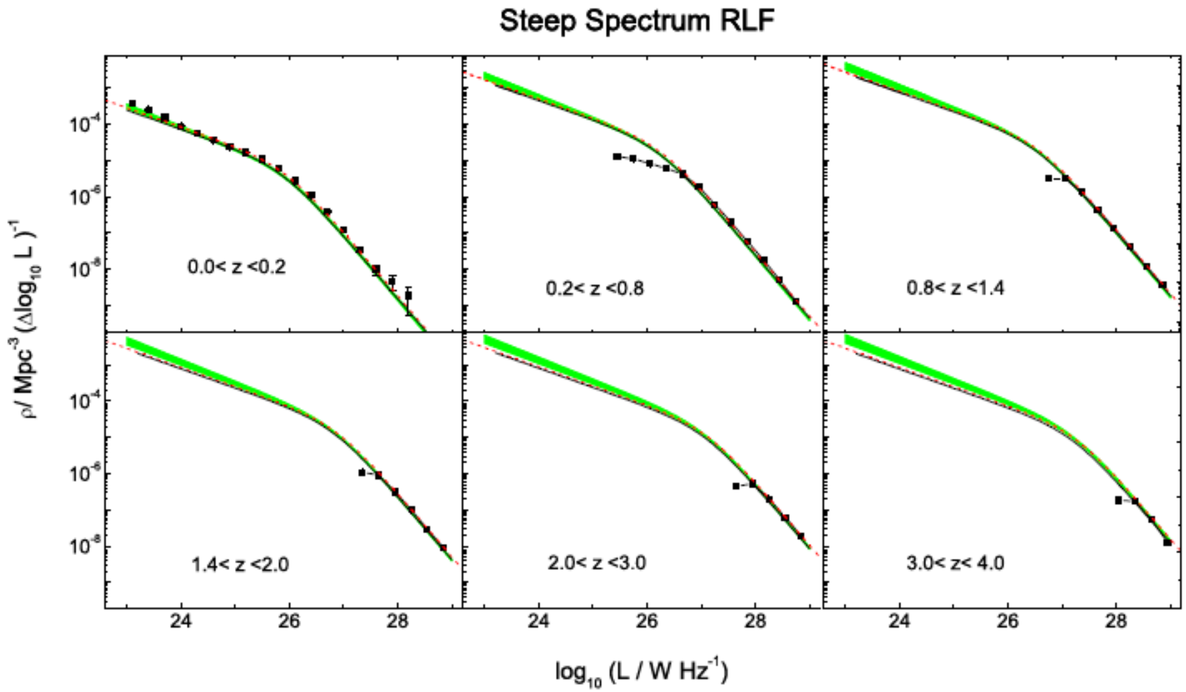


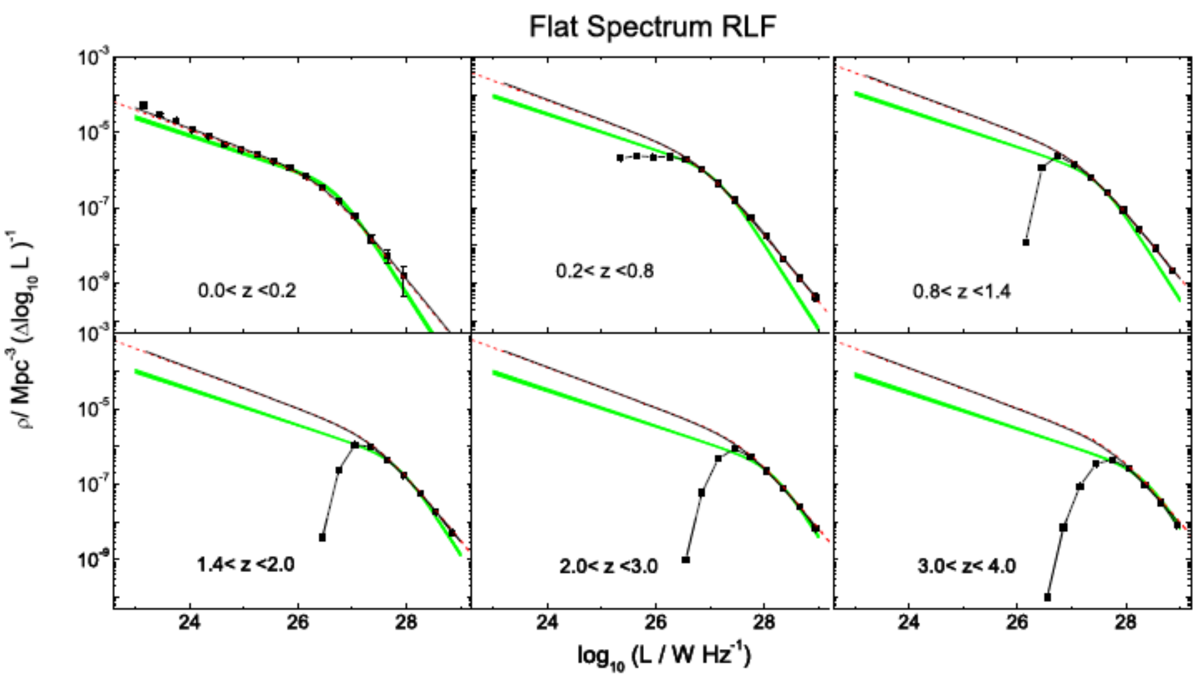
steep
α=0.52
α=0.75
α=0.98
flat
α=−0.2
α=0.2
α=−0.6
L
z

Effect of Spectral Index Distribution on Estimating the AGN Radio Luminosity Function

Yuan et al. ApJ, 2016, 829, 95







The classical 1/Va estimator can produce an artificial luminosity-dependent decline.

As a result of this distortion to the true RLF, the significance/degree of luminosity-dependent evolution is magnified, making a red-shift cut-off easier to find.

- The spectral index distribution is very important in estimating the AGNs RLF;

- We need to define a trivariate RLF, considering the spectral index distribution:

$$\Phi(\alpha, z, L) = \frac{d^3 N}{d\alpha dz dL}. \quad (1)$$

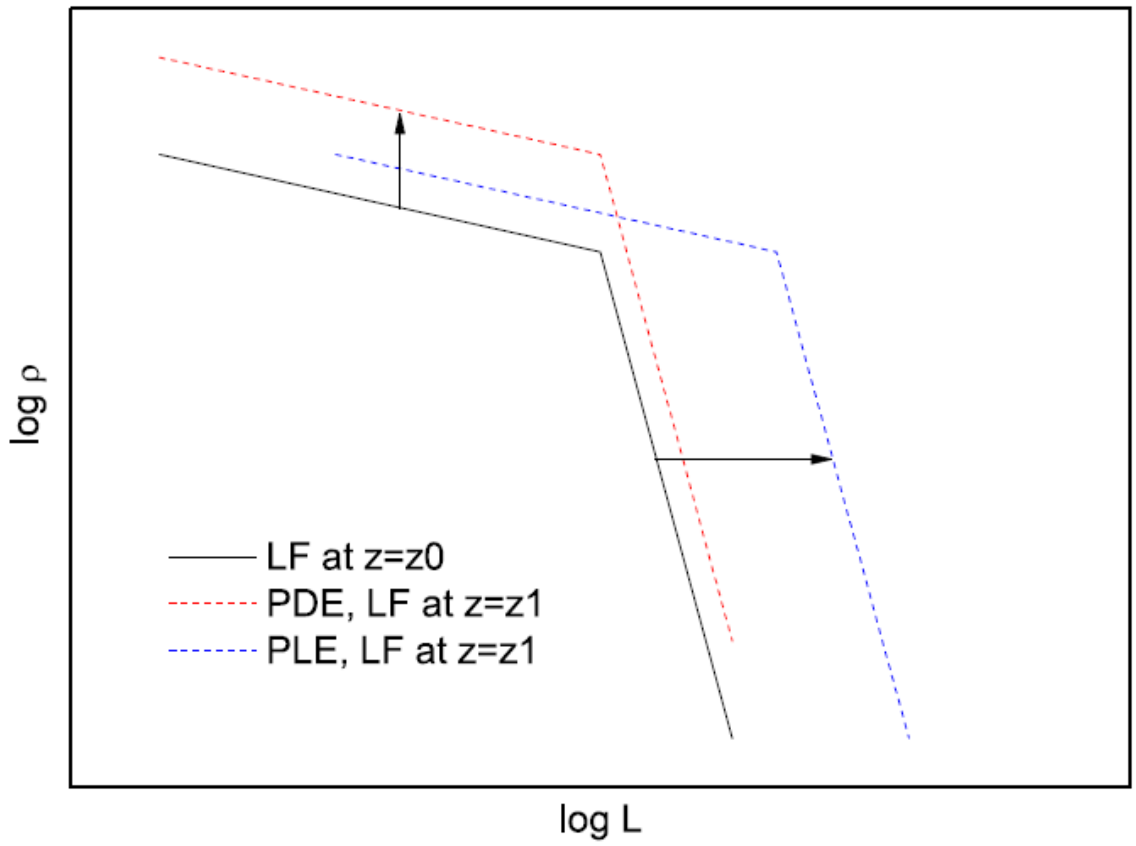
- It is defined as the number of sources per comoving volume V(z)、 with spectral indexes in the range α, α+d α, and with radio luminosities in the rangeL,L+dL.

Disengage the evolution degeneracy

- Once we have the above definition and concept, we try to disengage the evolution degeneracy.

- The key idea is that we consider a combination of density and luminosity evolution to describe the RLF.
- Mathematically, suppose the evolution of RLF is a vector ***E***, then it can be written as

$$\boldsymbol{E} = e_1\boldsymbol{E}_d + e_2\boldsymbol{E}_l$$



Intuitively understanding, the physical meaning of density evolution is whether the sources are more or less numerous than that of today,
while the luminosity evolution represents whether the sources are more or less luminous than that of today.

Our model

Our evolution model RLF can be written in the following general form.

$$\rho(z, L) = e_1(z)\rho(z = 0, L/e_2(z))$$

We did a lot of experiments, finally, we find the following model can fit the observed data very well.

- We model the density evolution $e_1(z)$ as a log-normal form:

$$e_1(z) = z_* + \frac{1}{z}\exp\left[-\frac{1}{2}\left(\frac{\ln z - z_0}{z_\sigma}\right)^2\right]$$

- The local luminosity function is

$$\rho(z=0, L/e_2(z=0)) = \frac{dN}{d\log L}$$
$$= \phi_0 \left(\frac{L}{L_*}\right)^{1-\gamma} \exp\left[-\frac{1}{2\sigma^2}\log_{10}^2\left(1+\frac{L}{L_*}\right)\right]$$

- The luminosity evolution is

$$e_2(z) = 10^{k_1 z + k_2 z^2}$$

- We also consider the effect of spectral index distribution of sample, and the intrinsic spectral index distribution is modeled as a log-normal form:

$$\frac{dN}{d\alpha} = \frac{1}{\alpha} \exp \left[-\frac{(\ln \alpha - \alpha_0)^2}{2\alpha_\sigma^2} \right]$$

- We find that a Gaussian form can also fit the data, but the log-normal form is better.

Bayesian Inference for the RLF Parameters

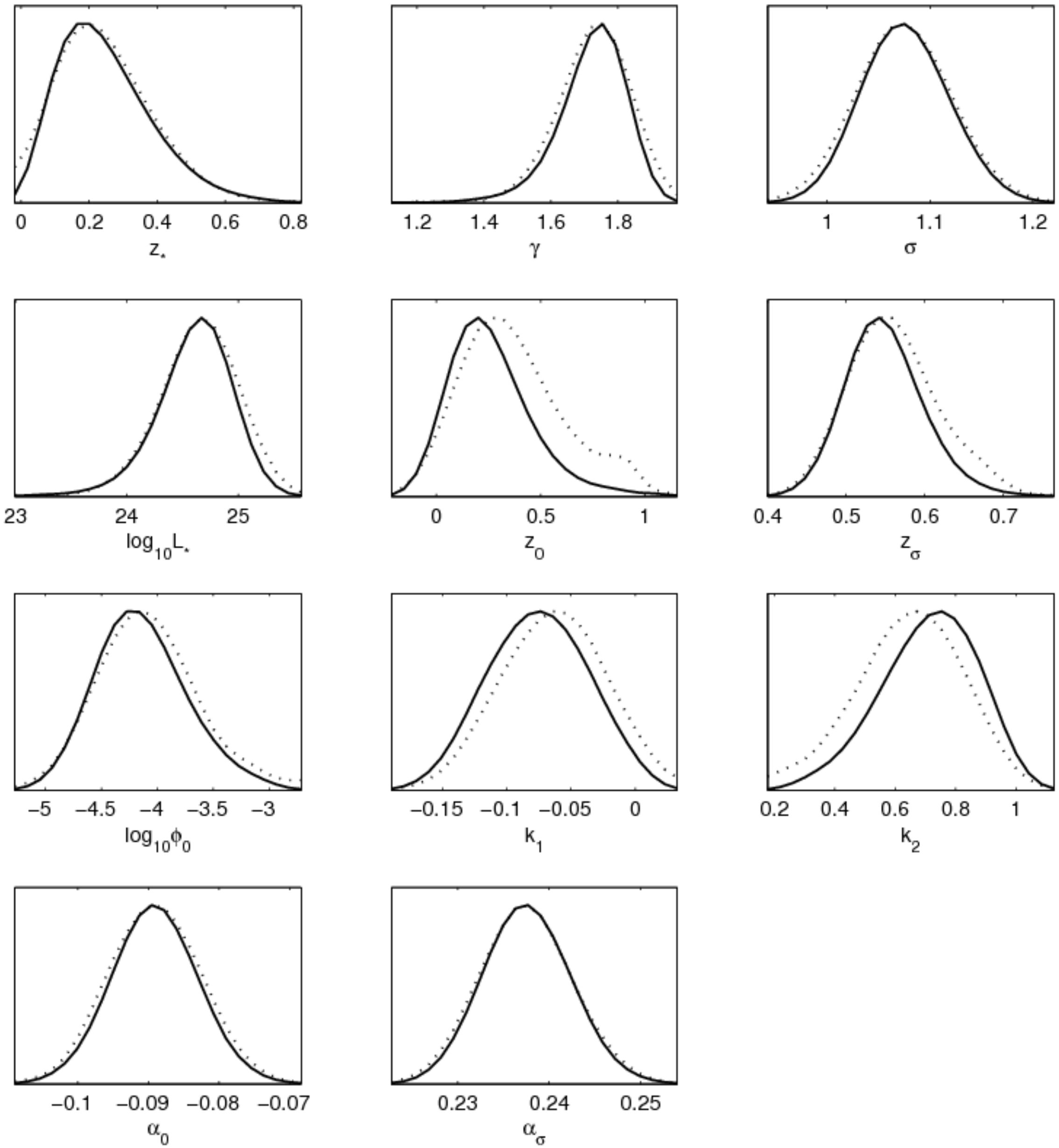
- Once given a RLF model, we can write the likelihood function $p(\alpha_{obs}, z_{obs}, L_{obs}|\theta)$.
- Let $S = -2\ln p(\alpha_{obs}, z_{obs}, L_{obs}|\theta)$, then

$$S = -2\sum_{i}^{N_{obs}} ln[\Phi(\alpha_i, z_i, L_i)] +$$

$$2\Omega \int_{\alpha_1}^{\alpha_2} d\alpha \int_{z_1}^{z_2} dz \frac{dV}{dz} \int_{max[L_1, L_{lim}(\alpha,z)]}^{L_2} \Phi(\alpha, z, L) dL$$

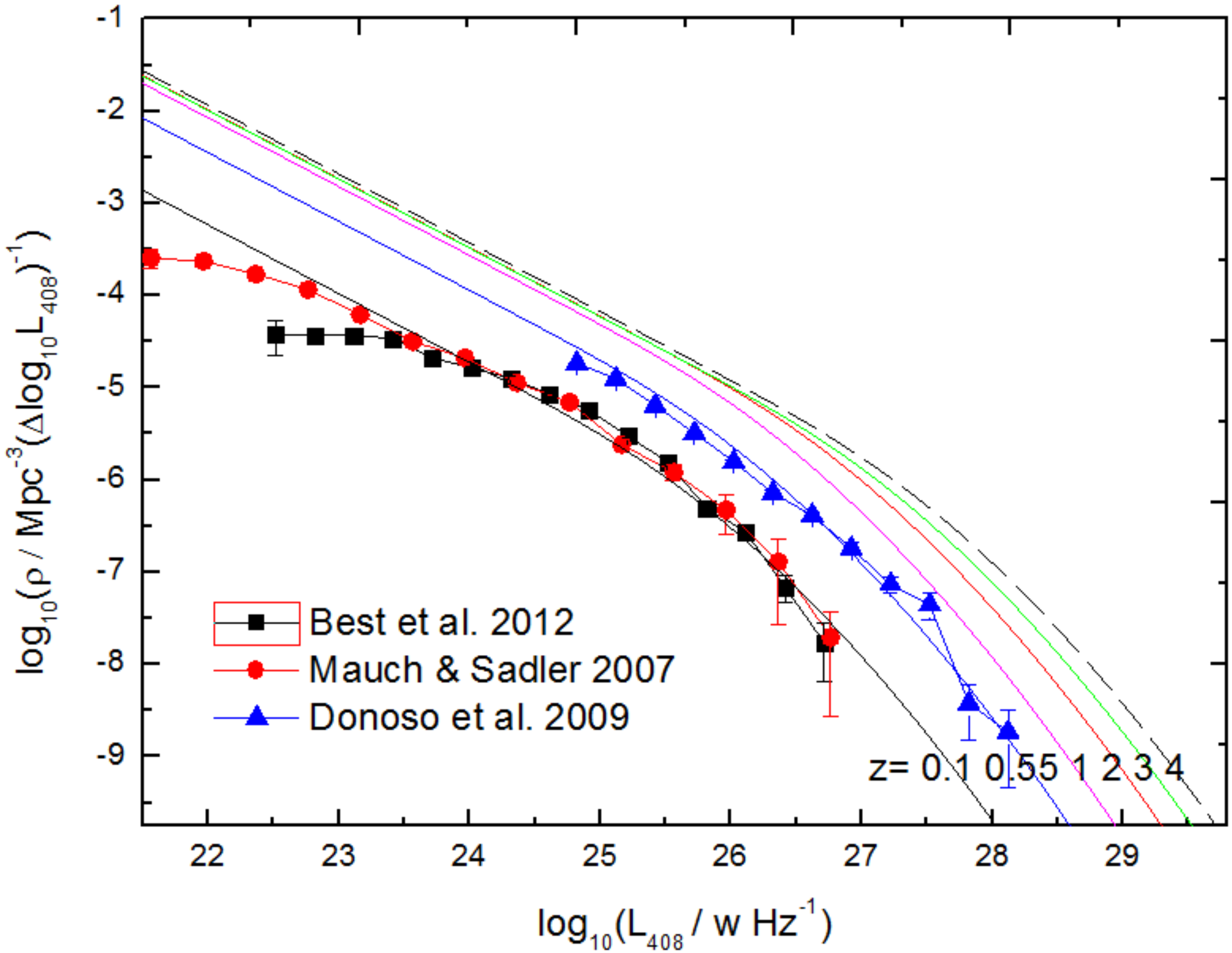
Based on the above likelihood function, and assuming a uniform prior on θ, we can obtain the best fitting parameters for our RLF model.

1D probability distribution of the parameters



The dash-dotted curves are the mean likelihoods of MCMC samples and the black solid curves are the marginalized probabilities.

The modeled steep-spectrum AGN RLF



- Our mixture evolution model works well, and the modeled RLFs are in good agreement with previous determinations.

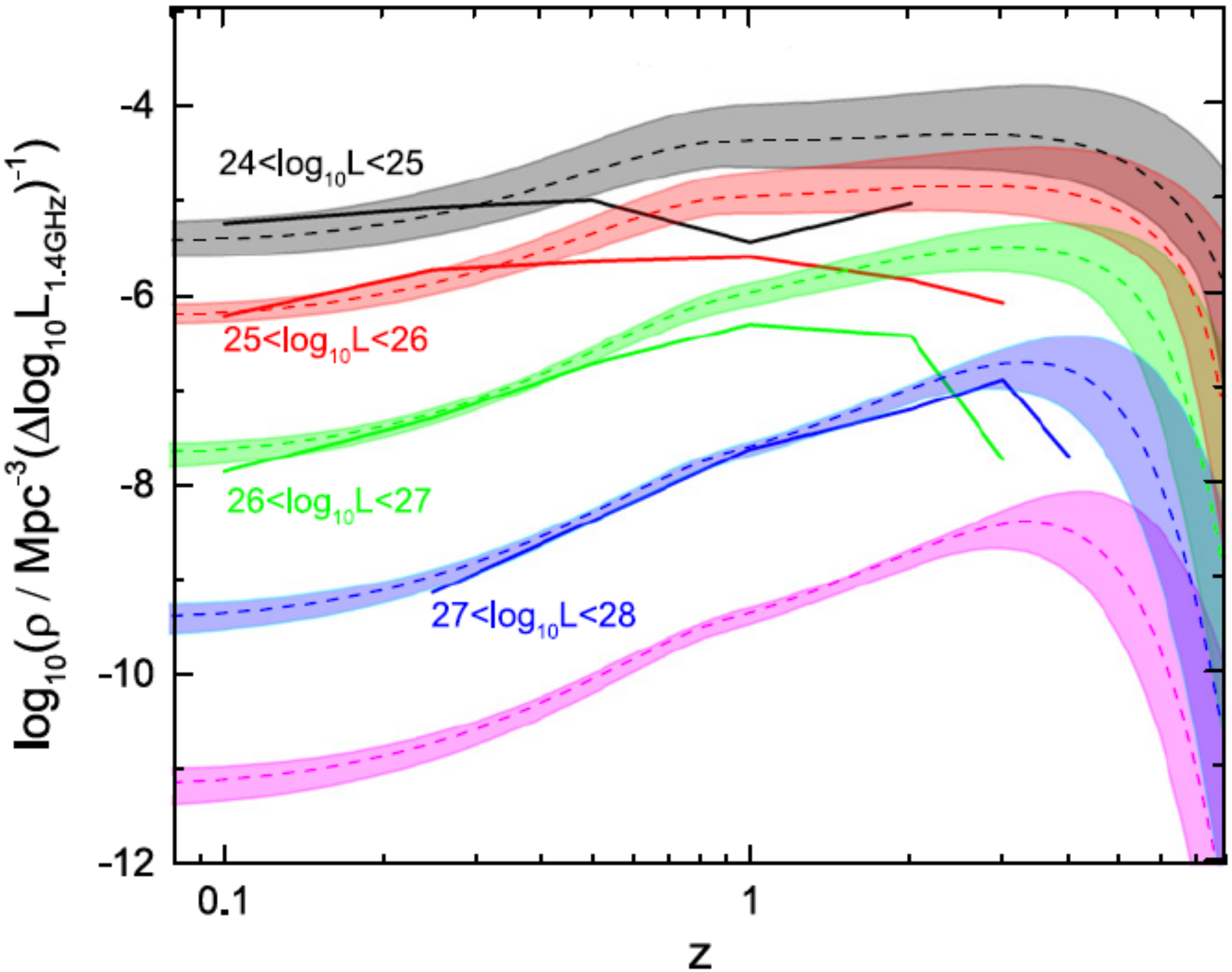
- We also perform a Kolmogorov–Smirnov (KS) test to estimate the goodness-of-fit of model.

GOODNESS-OF-FIT

Model	1D-P_{KS}-L	1D-P_{KS}-z	1D-P_{KS}-α
A	0.91	0.99	0.99

- The KS test result further support our model.

Luminosity-dependence of the High-redshift Turnover

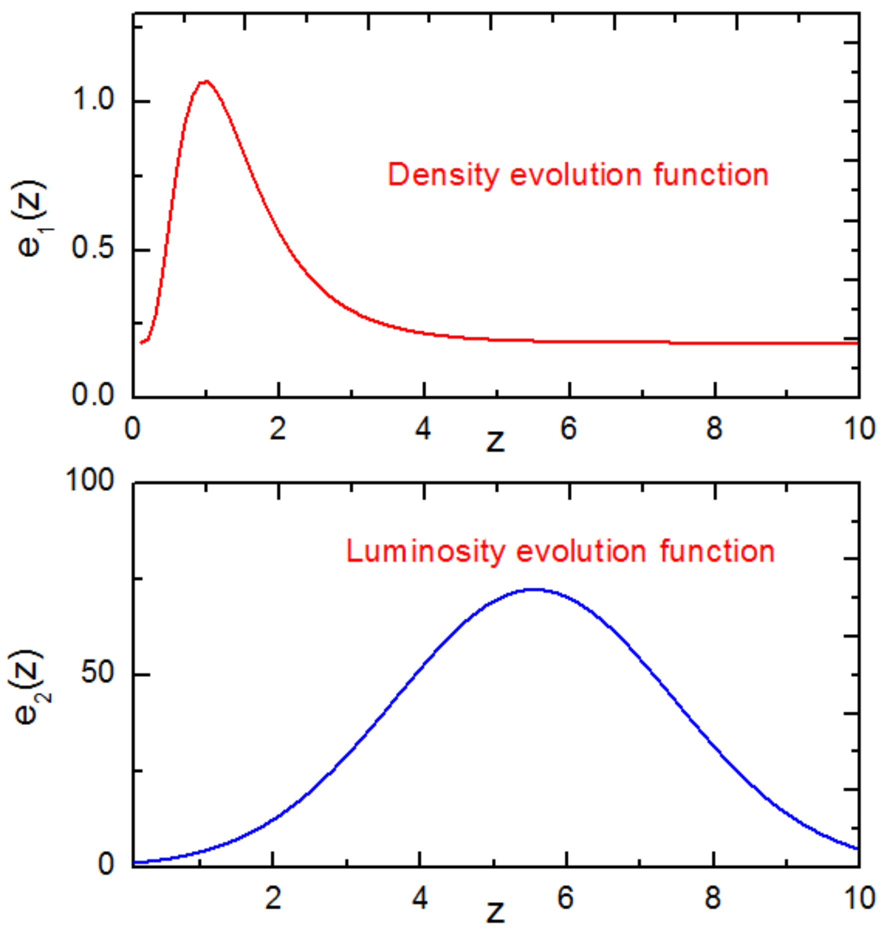


Yuan et al. 2016, ApJ, 820， 65

Our model RLF as functions of redshift. The light shaded areas take into account
the 1σ error bands. The black, red, green, and blue solid lines show the results
of Rigby et al. (2015)

- In recent years, evidence has suggested that the position of the steep-spectrum RLF peak is luminosity dependent (also known as the redshift cut-off problem).
- A recent evidence is given by Rigby et al. (2015).
- The above figure shows that our model is in broad agreement with the result of Rigby et al. (2015).
- But their result show a more significant Luminosity-dependent high-redshift turnover. (the effect of spectral index distribution? Yuan et al. 2016b)

The density evolution vs. luminosity evolution



the density evolution peaks at a redshift of z ~ 1

while the luminosity evolution is positive to a higher redshift z ~ 5

What's the physical meaning?

- The density evolution is associated with the density distribution of accreting black holes?

- The luminosity evolution is related with the changing of accretion state?

- just a speculation

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- This will be the subject of a future work.

summary

- We propose a mixture evolution scenario to model the steep-spectrum AGN RLF based on a Bayesian method. In this scenario, the shape of the RLF is determined together by the density and luminosity evolution.
- Our model indicate that the density evolution peaks at z~1, while the luminosity is positive to a higher redshift z~5.
- The mixture evolution scenario can naturally explain the luminosity-dependent evolution of the RLF.
- Our model support the existence of redshift cut-off, but the the turnover redshift should be greater than previous determinations.

Thanks for your attention !